

# CCD photometric study of the W UMa-type binary II CMa in the field of Berkeley 33

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## ABSTRACT

The CCD photometric data of the EW-type binary, II CMa, which is a contact star in the field of the middle-aged open cluster Berkeley 33, are presented. The complete R light curve was obtained. In the present paper, using the five CCD epochs of light minimum (three of them are calculated from Mazur et al. (1993)'s data and two from our new data), the orbital period  $P$  was revised to 0.22919704 days. The complete R light curve was analyzed by using the 2003 version of W-D (Wilson-Devinney) program. It is found that this is a contact system with a mass ratio  $q = 0.9$  and a contact factor  $f = 4.1\%$ . The high mass ratio ( $q = 0.9$ ) and the low contact factor ( $f = 4.1\%$ ) indicate that the system just evolved into the marginal contact stage.

*Subject headings:* Stars: binaries : close – Stars: binaries : eclipsing – Stars: individual (II CMa) – Stars: evolution

## 1. Introduction

II CMa, which was first discovered as a byproduct by Mazur et al. (1993) when they searched for variable stars in the intermediate age open cluster Berkeley 33, is a W UMa-type contact binary in the field of the cluster (Berkeley 33,  $\alpha_{2000.0} = 06^h57^m42^s$ ,  $\delta_{2000.0} =$

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13°13'00", either named as Ruprecht 7). They marked it as  $v_1$ , and classified it into EW-type. It was named as II CMa by the latest version of the General Catalogue of Variable Stars (GCVS for short, Samus et al. 2004). It is very clear to see a O'Connell effect (O'Connell, 1951) in Mazur et al.'s V, I lights. The amplitude in V & I magnitude were both 0.5 mag according to Mazur et al. 1993. They also gave its period as 0.2292 days, (V-I) as 1.44, (B-V) as 1.3. They concluded that II CMa is probably a foreground contact binary, of later type, similar to the well-studied system CC Com and V523 Cas. The other research about it came from Rucinski (1998). Having used  $E(B - V)_{Be33} = 0.7$ ,  $(B - V)_{II\ CMa} = 1.30$ , Rucinski (1998) pointed out the contact binary star II CMa is definitely not members of the cluster Be 33.

## 2. Observations for II CMa

After observed on two nights (February 19, 21, 2007) with the PI1024 TKB CCD photometric system attached to the 1.0-m reflecting telescope at the Yunnan Observatory in China, the data in R band of II CMa were obtained. The R color systems used are close to the standard UBVRI system and the effective field of view of the photometric system is  $6.5 \times 6.5$  arc min at the telescope's Cassegrain focus. The integration time for each image is 150 s. PHOT (measure magnitudes for a list of stars) of the aperture photometry package of IRAF was used to reduce the observed images.

The observations in the R passband completely cover the orbital phase. We calculated the phase of the observations with the linear ephemeris (Eq.1) given in next section, and plotted the R light in Figure 1. Our original data in the R band are listed in Table 1. The light curve is continuous and possesses a very small difference between the depths of minima which reveal the system was tidally distorted and both components' temperature may be similar. The maximum brightness is 15.22mag in V passband and the amplitude of the light variation is  $\sim 0.45$  mag. Since the two minima in the curve show a sharp variation, those properties suggest that the system has a low orbital inclination and the size of the two components might be similar. We also plotted the comparison and the check star's corresponding curve in Figure 1. It is a straight line showing that the comparison star is constant and the variation of the curve upon plate in Figure 1 truly came from II CMa. Corresponding coordinates of the binary, comparison and check star are listed in Table 2. We chose the comparison star as close to the variable as it can where the range of air-mass difference between both stars was very small ( $\sim 0.0007$ ). Therefore, extinction correction was not made. It is shown in this figure that the data are high quality except for several data points and the light variation is typical of EW-type. Due to the light minimum is symmetric,

a parabolic fitting was adopted to determine the times of minimum light with a least square method. Two epochs of light minimum were obtained in all and are listed in the last two rows of Table 3.

There are some obvious variations in the light curves, such as O’Connell effect, eclipse depth at minimum. It is very clear to see a O’Connell effect (O’Connell, 1951) in Mazur et al.’s V, I lights. Namely the magnitude of 0.75 phase is about 0.022 mag bright than that of the 0.25 phase in I light. In V light, the O’Connell effect is the same as I light, but the value is slightly smaller than 0.022 mag, it is about 0.02 mag. We can call that as negative O’Connell effect. However, it disappeared now. Another variation in the light curve is that the amplitude in V magnitude was 0.5 mag according to Mazur et al. 1993, while that in R is 0.45 mag now. Although observed in different passband, noting that wavelength of R band is between that of V band and I band, we have sufficient reasons to believe the light curve changes. On the other hand, this kind of changes are frequently seen in W UMa-type binaries. For instance, FG Hya (Qian & Yang, 2005), AH Cnc (Qian et al. 2006), EQ Tau (Yang & Liu, 2004), CU Tau (Qian et al. 2005), AD Cnc (Yang & Liu, 2002a), QX And (Qian et al. 2007), CE Leo (Yang & Liu, 2002b, Kang et al. 2004), BX Peg (Lee et al. 2004).

### 3. New ephemeris of II CMa

There were too lack of studies about II CMa to investigate its period changes. Consequently, we can only revise the linear ephemeris. By setting the initial period value as 0.2292 days declared by Mazur et al. (1993) and combining the three times of minimum calculated from Mazur et al. (1993)’s data and two of ours, we determined a new linear ephemeris as follows,

$$\begin{aligned} \text{Min. I} = & 2454153.0961(\pm 0.0008) \\ & + 0.^d22919704(\pm 0.00000004) \times E, \end{aligned} \tag{1}$$

and it is suggested that the much more accurate period should be 0.22919704 days. The correction about  $-0.00000296$  days were made. After amended, that new linear ephemeris given by us is more precise than before, which can forecast the times of minimum about II CMa in the future. The phases of the observations and the  $(O - C)$  values were calculated through that Equation (See Table 3).

Table 1: Photometric Data in the R band for II CMa observed with the 1.0 meter telescope at Yunnan observatory on February 19, 21, 2007

JD.Hel.	$\Delta m$	JD.Hel.	$\Delta m$	JD.Hel.	$\Delta m$	JD.Hel.	$\Delta m$	JD.Hel.	$\Delta m$
2454100+		2454100+		2454100+		2454100+		2454100+	
51.0623	1.374	51.1160	1.392	51.1686	1.480	51.2226	1.382	53.0843	1.618
51.0646	1.373	51.1181	1.409	51.1707	1.476	51.2249	1.388	53.0863	1.656
51.0673	1.351	51.1203	1.406	51.1728	1.458	51.2269	1.379	53.0882	1.657
51.0693	1.348	51.1224	1.430	51.1749	1.440	51.2290	1.406	53.0903	1.695
51.0714	1.347	51.1245	1.464	51.1770	1.466	51.2312	1.398	53.0922	1.708
51.0735	1.326	51.1266	1.494	51.1791	1.437	51.2333	1.403	53.0942	1.735
51.0756	1.330	51.1286	1.510	51.1812	1.438	51.2354	1.437	53.0962	1.729
51.0777	1.336	51.1307	1.525	51.1837	1.401	51.2376	1.461	53.0981	1.744
51.0798	1.333	51.1328	1.556	51.1858	1.383	51.2398	1.494	53.1001	1.716
51.0818	1.326	51.1349	1.580	51.1879	1.362	53.0523	1.324	53.1021	1.686
51.0839	1.325	51.1370	1.585	51.1900	1.349	53.0544	1.348	53.1041	1.679
51.0860	1.313	51.1391	1.638	51.1921	1.338	53.0564	1.336	53.1060	1.634
51.0881	1.318	51.1412	1.673	51.1942	1.317	53.0584	1.371	53.1080	1.619
51.0902	1.326	51.1433	1.703	51.1962	1.320	53.0603	1.359	53.1100	1.589
51.0922	1.307	51.1455	1.720	51.1983	1.314	53.0623	1.391	53.1122	1.576
51.0944	1.311	51.1476	1.691	51.2004	1.312	53.0643	1.381	53.1143	1.548
51.0964	1.316	51.1497	1.686	51.2033	1.320	53.0664	1.414	53.1164	1.521
51.0985	1.332	51.1518	1.666	51.2054	1.313	53.0684	1.414	53.1185	1.496
51.1006	1.326	51.1539	1.665	51.2075	1.309	53.0703	1.441	53.1205	1.485
51.1027	1.330	51.1560	1.635	51.2096	1.312	53.0723	1.443	53.1225	1.481
51.1055	1.350	51.1581	1.620	51.2117	1.339	53.0744	1.473	53.1244	1.456
51.1076	1.316	51.1601	1.614	51.2140	1.308	53.0763	1.487	53.1264	1.429
51.1098	1.332	51.1622	1.565	51.2161	1.328	53.0784	1.518	53.1284	1.424
51.1118	1.334	51.1644	1.538	51.2182	1.347	53.0803	1.554		
51.1139	1.355	51.1665	1.514	51.2205	1.354	53.0823	1.559		

Table 2: Coordinates of II CMa, the comparison, and the check stars.

Stars	2MASS
II CMa	06573640-1314364
The comparison	06573261-1314336
The check	06573952-1312477

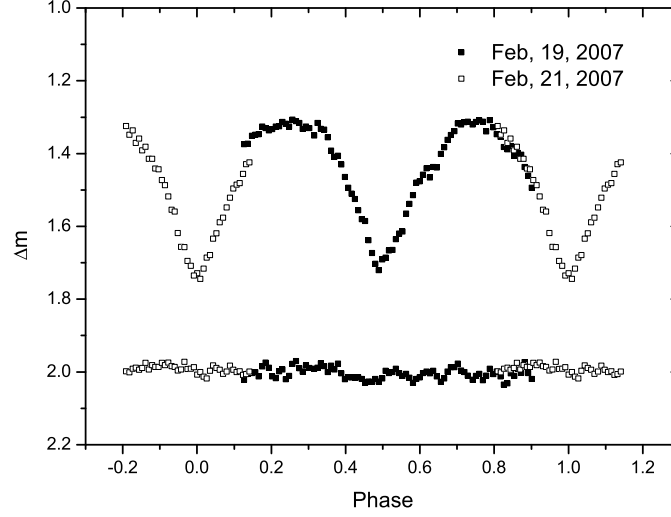


Fig. 1.— CCD data in the R band of II CMa observed at 19 and 21 February, 2007.

Table 3: CCD times of light minimum for II CMa.

JD.Hel.	Error (days)	Filters	Min.	E	( $O - C$ )	Origin
2448253.2205	$\pm 0.0009$	V	II	-25741.5	+0.0000	Mazur et al. (1993)’s data
2448286.1117	$\pm 0.0011$	I	I	-25598	+0.0014	Mazur et al. (1993)’s data
2448291.1511	$\pm 0.0011$	I	I	-25576	-0.0015	Mazur et al. (1993)’s data
2454151.1480	$\pm 0.0004$	R	II	-8.5	+0.0000	The present paper
2454153.0961	$\pm 0.0003$	R	I	0	+0.0000	The present paper

#### 4. Photometric Solution

Neither the photometric nor the spectral parameters of II CMa have been derived before. So, the initial values must be estimated, such as temperatures, mass ratio, and otherwise. Because it appears in the field of the cluster Be 33, they might got similar extinction. So we need to know some information about the cluster.

There are several authors had study the middle-aged open cluster Berkeley 33 (Mazur et al. 1993, Lata et al. 2002, Hasegawa et al. 2004, Carraro et al. 2005). Mazur et al. (1993), Lata et al. (2002) derived the cluster’s  $E(B - V)$  and distance modulus were 0.70 and 15.5 respectively. However, recently, Hasegawa et al. (2004), Carraro et al. (2005) have suggested that the corresponding parameters mentioned above were 0.3 and 15.0. It is obvious that there are two groups of measured parameters. The data published in earlier years are group one, and in later years are definitely group two. In order to compare these two different groups, we listed them in Table 4.

However, the distance modulus of Hasegawa et al. (2004) is 14.2, and the age is 1.3Gyr, which are very different from the other three values. As they said, that was the most difficult cluster in their sample to fix the cluster parameters, so that their efforts might not give a convincing fit.

Considering the two different group parameters (Table 4), the discussions were under two cases, namely Case A and Case B.

(i) Case A, the color excess is  $E(B - V) = 0.7$ , and the corresponding temperature is 5800K by used the well known experiential formula,

$$T = 8540 / [(B - V)_0 + 0.865], \quad (2)$$

where  $(B - V)_0 = (B - V) - E(B - V)$ .

(ii) Case B, the color excess is  $E(B - V) = 0.3$ , and the corresponding temperature is 4579K.

Table 4: The different parameters of Berkeley 33.

$E(B - V)$	$E(V - I)$	$(m - M)$	Age(Gyr)	$[Fe/H]$	Reference
0.70		15.5	0.7	-0.6	Mazur et al. 1993
0.70		15.6	0.7		Lata et al. 2002
0.30	0.50	14.2	1.3	0.008	Hasegawa et al. 2004
0.30	0.47	15.0	0.8	0.019	Carraro et al. 2005

On the other hand, as Eggen having pointed out in 1967 (Eggen, 1967), for contact binaries, there is a strict relationship between color and period, namely  $C = -0.50 - 2.26 \log P$ . Hence, we can obtain the color-index as 0.946, which much better corresponds to the Case B. As a result of that, we assumed the primary component's temperature is  $4579K$ .

In order to get a probable value of the mass ratio  $q$ , a q-search method with the 2003 version of the W-D program (Wilson & Devinney, 1971; Wilson, 1990, 1994; Wilson & Van Hamme, 2003) was used (Figure 2). Firstly, we fixed  $q$  to 0.2, 0.3, 0.4 and so on in both of Case A and Case B, as figure 4 shows. It can be seen that the value of  $q$  is a range from 0.3 to 0.8. Thought about the characters of the light curve, as mentioned above (Section 2), we incline to the value  $q = 0.9$ .

During the solution, the bolometric albedo  $A_1 = A_2 = 0.5$  (Rucinski 1969) and the values of the gravity-darkening coefficient  $g_1 = g_2 = 0.32$  (Lucy 1967) were used, which correspond to the common convective envelope of both components. Limb-darkening coefficient of 0.499 in R under Case A and 0.645 in R under Case B were used, according to Claret & Gimenez (1990). The adjustable parameters were, the mass ratio  $q$ ; the orbital inclination  $i$ ; the mean temperature of star 2,  $T_2$ ; the monochromatic luminosity of star 1,  $L_{1R}$ ; and the dimensionless potential of star 1 ( $\Omega_1 = \Omega_2$ , mode 3 for contact configuration). The results of the photometric solutions are listed in Table 5 and the theoretical light curves computed with those photometric elements are plotted in Figure 3. Meanwhile, the geometrical structure of II CMa is displayed in Figure 4.

## 5. Discussion and Conclusion

After two nights' (Feb 19, 21, 2007) observations, the complete R light was obtained. It is very easy to find that there exist some distinct changes about O'Connell effect (O'Connell, 1951), which consist in many W UMa-type binaries such as FG Hya (Qian & Yang, 2005), AH Cnc (Qian et al. 2006), EQ Tau (Yang & Liu, 2004), CU Tau (Qian et al. 2005), AD Cnc (Yang & Liu, 2002a), QX And (Qian et al., 2007), CE Leo (Yang & Liu, 2002b, Kang et al. 2004), BX Peg (Lee et al. 2004), and so on. A O'Connell effect (O'Connell, 1951) of II CMa was in Mazur et al.'s V, I lights. The magnitude of 0.75 phase is about 0.022 bright than that of the 0.25 phase in I light. In V light, the O'Connell effect is the same as I light, but the value is slightly smaller than 0.022, it is 0.02. But we did not find distinctness in our light curve.

Using the five times of minimum of II CMa listed in Table 3, the orbital period was revised as 0.22919704 days. The system is a high mass ratio shallow contact binary with

Table 5: Photometric Solutions for II CMa.

Parameters	Photometric elements	errors
$g_1 = g_2$	0.32	assumed
$A_1 = A_2$	0.50	assumed
$x_{1R} = x_{2R}$	0.645	assumed
$T_1$	4579K	assumed
$q$	0.9000	assumed
$\Omega_{in}$	3.5856	–
$\Omega_{out}$	3.0880	–
$T_2$	4475K	$\pm 29$ K
$i$	68.276	$\pm 0.415$
$L_1/(L_1 + L_2)(R)$	0.5534	$\pm 0.0405$
$\Omega_1 = \Omega_2$	3.5653	$\pm 0.0192$
$r_1(pole)$	0.3676	$\pm 0.0030$
$r_1(side)$	0.3871	$\pm 0.0039$
$r_1(back)$	0.4189	$\pm 0.0058$
$r_2(pole)$	0.3500	$\pm 0.0032$
$r_2(side)$	0.3676	$\pm 0.0040$
$r_2(back)$	0.4002	$\pm 0.0062$
the contact factor $f$	4.1 %	$\pm 0.8$ %
$\sum \omega_i (O - C)_i^2$	0.006279	



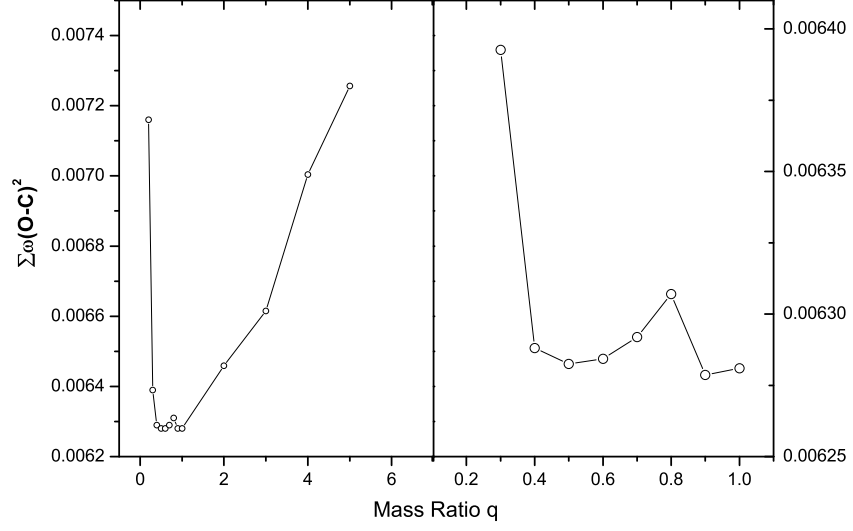


Fig. 2.— The relation between  $q$  and  $\Sigma$  for II CMa, the right panel is the megascopic corresponding field in the left panel.

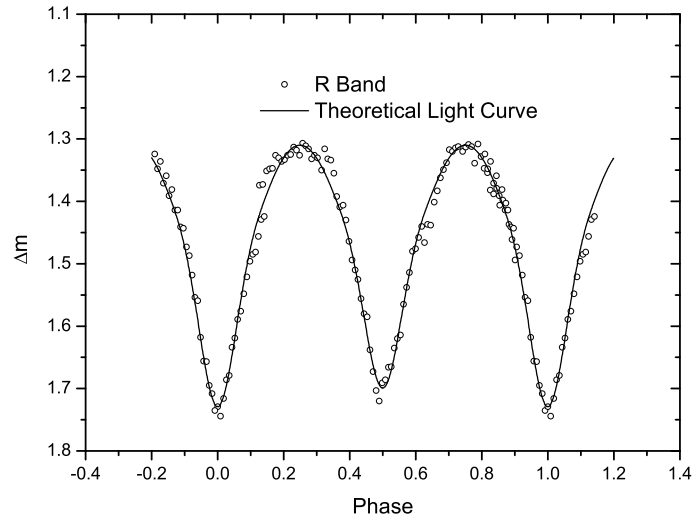


Fig. 3.— Observed and theoretical light curves in the R band for II CMa.

$q = 0.9$ ,  $f = 4.1\%$ . These suggest that the system is a marginal contact binary. There are a hundreds of difference temperatures between the two components, that phenomena was usually in contact binaries.

High mass ratio, low contact factor contact systems, which are much more interest and important, are the key to understanding the evolution status of a close binary from the near contact phase to the contact phase. Nearly, almost all acceptable models of contact binary foretell that while contact age is increasing,  $q$  is decreasing. This is on account of ineluctable mass transfer from the less mass component to the more one when the system came to the contact stage. Although there are two assumed cases about the system, both the mass ratio and the low contact factor suggest that II CMa is just come into contact so that it has younger contact age. This kind of contact binaries which were called marginal contact binaries ( $f \leq 10\%$ ) are indicators of evolution time scale into the contact stage. For example, V803 Aql (Samec et al. 1993), FG Sct (Bradstreet, 1985), RW PsA (Lucy & Wilson, 1979), XZ Leo (Niarchos et al. 1994), S Ant (Russo et al. 1982). These marginal contact binaries' parameters are list in Table 6.

II CMa would not be a member of Be33 for two reasons. Firstly, according Rucinski's (1998) result,  $M_v = -4.44\log P + 3.02(B - V)_0 + 0.12$ , its distance modular is 9.32, which indicates this system is in front of the cluster in space. Secondly, assumed it is a cluster member, noticing that the binary II CMa appears at the red giant Branch in the cluster's Color-Magnitude Diagram, it should be a red giant system. But based on the theory of structure and evolution of stars, it hardly to explain how such system who possesses a typical EW-type light curve be born. So, we prefer that II CMa is a front field star. It is remarkable that II CMa and the cluster have same interstellar extinction (see previous sections), which may imply there is a big extinction matter in front of them.

Colligating the reasons above, we can say that the W UMa-Type high mass ratio shallow contact binary in the intermediate-aged open cluster Berkeley 33 field II CMa is a very interesting object to be study. It will be helpful to understand something about marginal

Table 6: Parameters of some marginal contact binaries ( $f \leq 10\%$ )

Name	Period	$T_1$ (K)	$T_2$ (K)	$i(^{\circ})$	$q$	$f\%$	ref.*
V803 Aql	0.2634	4600	4594	82.910	1.0	8	(1)
FG Sct	0.27057192	4800	4662	89.9	1.273	8.5	(2)
RW PsA	0.36045011	5600	5325	77.45	0.813	7	(3)
XZ Leo	0.48773526	7850	7044	72.035	0.726	7	(4)
S Ant	0.6483358	7800	7340	69.49	0.590	9	(5)
II CMa	0.22919704	4579	4475	68.276	0.900	4.1	(6)

References in Table 6: (1) Samec et al. (1993); (2) Bradstreet (1985); (3) Lucy & Wilson (1979); (4) Niarchos et al. (1994);

(5) Russo et al. (1982); (6) The present authors.

contact binaries.

Eventually, since the eclipse binary is partial and absolute physical dimensions are still uncertain yet, it can not take the purely light solution as a definition. It is just a reasonable result. Only will precision radial-velocity curves put our result on a strong footing. In the future, for identify its identity strictly, a precise spectra observation is needed, which may help us to make sure weather it a member or not. Speaking for itself, this would be the most important element we need to know, otherwise all the works purely stood on a assumption. And another thing, we should accumulate the times of its minimum in order to investigate its orbital period changes, which can open out its evolution stage. In a word, it is essential to monitor the every interesting high mass ratio low contact factor contact binary system II CMa.

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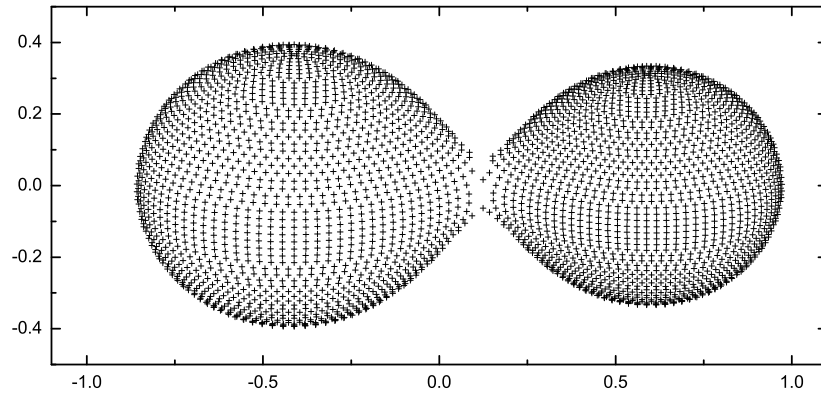


Fig. 4.— Geometrical structure of the high mass ratio shallow contact binary II CMa.